Technical Note N-734

A PROPOSED SYSTEM FOR SUPPLYING AIR TO A HYPOTHETICAL UNDEROCEAN SEABEE BASE. II. THE VENTURI GAS EXCHANGER

By

Harold P. Vind, Ph. D. and Arthur Langguth

16 June 1965

U. S. NAVAL CIVIL ENGINEERING LABORATORY
Port Hueneme, California

A PROPOSED SYSTEM FOR SUPPLYING AIR TO A HYPOTHETICAL UNDEROCEAN SEABEE BASE. II. THE VENTURI GAS EXCHANGER

Y-R011-01-01-058

Type C

by

Harold P. Vind, Ph. D., and Arthur Langguth

ABSTRACT

A device called a "venturi gas exchanger" was designed and constructed. The function of the device is to continuously scrub the interior atmosphere of a simulated underwater chamber in sea water. The only source of oxygen in the experimental chamber is that removed from the sea water during the scrubbing process, and the only means for removing carbon dioxide from the chamber is the same scrubbing process. A micro-burner can be kept burning indefinitely in the chamber; and two rats were maintained in the chamber for an entire eight hour day. During their stay in the chamber, the rats appeared to be comfortable and they suffered no discernible ill effects from the experience. Future plans call for the construction of a submersible model of the venturi gas exchanger which will be employed to ventilate a submerged chamber.

INTRODUCTION

Before he can successfully occupy underwater structures, man must first devise a simple and dependable system for supplying himself with air when he is underwater.[1] Design of such a system should not be deferred until after the structures have been erected, for the design of a system for maintaining an habitable atmosphere within underwater structures may be more challenging and time consuming than the design of the structures themselves.

Potentially, one of the most dependable and practical methods for bringing air to an underwater structure is via a pipeline from a shore based pumping station. Where bottom topography permits, such methods are feasible even where underwater structures are a considerable distance from the shore, for gases can be piped great distances without difficulty.

A less dependable though perhaps more practical method for bringing air to underwater structures is through a hose from a floating pumping station. Lack of dependability of floating pumping stations was illustrated by the recent "sea lab" trials near Bermuda.[2,3] A storm interrupted the trials and nearly caused a tragedy insofar as the surface vessel supplying the vital mixture of oxygen and helium could not operate during a storm. However, even though they are unreliable, surface pumping stations are, nevertheless, very practical as components of a "redundant" system for supplying air and oxygen to submerged structures.

When sufficient power is available, oxygen can be generated by the electrolysis of sea water. Though not without their faults, electrolytic oxygen generators are at the present time the most highly developed devices for supplying oxygen underwater. They supply no nitrogen, however, and do not remove carbon dioxide and other toxic gases produced in a closed environment. The nitrogen component of the air that escapes, or that is used for such purposes as operating air locks or for charging scuba tanks, cannot be replaced by the electrolysis of water. Furthermore, considerable auxiliary air processing equipment is required to remove hydrogen, carbon dioxide, and other toxic gases.

The earth's atmosphere is revitalized by the photosynthetic activity of green plants, which produce oxygen and consume carbon dioxide. A number of laboratories[4,5] are attempting to imitate nature by employing photosynthetic gas exchangers for revitalizing submarine or space ship atmospheres. Mass cultures of algae are grown under artificial light, and the air to be purified is bubbled through the cultures.

Though such exchangers very effectively perform the desired exchange of gases, they require the expenditure of around 30 kilowatts of power per man just for the photosynthetic process. Additional power is required for circulating water and processing the air. The abnormally high consumption of power is required in consequence of the limited effeciency in the conversion of electrical energy to light energy. For space travel the latter problem would not be encountered, as sunlight would be employed in lieu of artificial light. Unless far more efficient means are found for converting electrical energy to light energy, however, the use of photosynthetic gas exchangers for ventilating underwater structures does not appear to be practical.

The feasibility of utilizing the air dissolved in sea water as a source of oxygen for manned underwater structures, and subsequently utilizing the deoxygenated sea water as a vehicle to remove waste gases, is being studied at the General Electric Research Laboratory,[6] and at the U. S. Naval Civil Engineering Laboratory.[1] The former laboratory is testing devices for bringing about an exchange of gases through a special silicone-rubber membrane which permits the passage of oxygen, carbon dioxide, nitrogen, and water vapor, but does not permit passage of appreciable quantities of water. At the General Electric Research Laboratory, small rodents have been kept alive for nearly two weeks in a submerged chamber ventilated via the special membrane. The U. S. Naval Civil Engineering Laboratory, on the other hand, is testing simple devices for effecting the desired exchange of gases by bringing the sea water and air into intimate contact in the form of a finely dispersed mixture. The NCEL proposal is to bring sea water into the underwater structure, then to process the sea water for the recovery of oxygen and the disposal of carbon dioxide and other waste gases, and finally to discharge the carbonated and deoxygenated sea water back into the ocean environment. Though the equipment required for the General Electric and NCEL processes differs considerably the investigations at the two laboratories have the common goal of demonstrating the feasibility of ventilating underwater structures by scrubbing their interior atmospheres with sea water.

The advantage of the General Electric membrane process is that relatively little energy is required. The sea water need not be pumped against the pressure of submergence, but need merely be circulated past the membrane. However, regardless of the membrane's thinness, its presence at the air and sea water interface does retard the diffusion of gases

across that interface. Even the presence of a monomolecular film on the surface of a body of water, for example, will markedly retard evaporation. In the NCEL process, diffusion of gases occurs almost instantaneously as there are no membranes through which the gases must penetrate. Furthermore, the surface area of the droplets and bubbles is very great, and the distances through which the gases must diffuse are very short. Hence, even though it must be pumped against the pressure of submergence, large volumes of sea water can be processed by the NCEL procedure with relatively compact equipment. Successful development of the NCEL pressure-reducing pump[7] - Navy patent disclosure number 38365 - would eliminate the need to pump against the pressure of submergence.

STATEMENT OF PURPOSE

The purpose of the investigation described in this series of Technical Notes is to ascertain the feasibility of employing the NCEL proposed sea water process for ventilating a hypothetical underocean seabee base or for supplying air to seabees working underwater. The immediate purpose of this second Technical Note is to present experimental evidence that a sea water process can be employed to ventilate closed chambers.

APPROACH TO THE PROBLEM

An experimental approach is being employed to demonstrate the feasibility of the NCEL Sea Water Process for ventilating undersea structures. The first step in the feasibility study has been completed and is described in this Technical Note. These experiments demonstrate that a sea water process can be employed to renew the air in a small enclosure in which a small flame or small animals are maintained. The second step will be to repeat the same demonstration with apparatus that, except for an electric power cord, will be submerged in water. The proposed third step will be to construct a gas exchanger sufficiently large to renew the air used by one man breathing through a face mask. The proposed fourth step of the feasibility study will be to submerge the apparatus, and with it, to supply air to a submerged manned enclosure. The enclosure will be nothing more elaborate than an inverted box large enough to accomodate the head, shoulders, and upper half of the man. For a final evaluation of the process, however, it will be necessary to test working models of the apparatus at the maximum depth to which the process will be used.

EXPERIMENTAL DEVELOPMENT

A hypothetical three-stage process for obtaining air from sea water was described in the previous Technical Note in this series.[1] The process would presumably avoid the need to pump the sea water against the pressure of submergence. However, the development and construction of apparatus for the three-stage process would have been far too great an undertaking for a feasibility study. Therefore, simpler gas exchange devices were constructed as part of an effort to demonstrate that, when he is under water, man might obtain air for breathing by recovering dissolved oxygen from sea water and discharging carbon dioxide to the same medium.

Countercurrent gas exchanger. Two countercurrent gas exchangers, shown diagrammatically in Figure 1, were constructed. The first and smaller exchanger was mounted on a portable cart and was designed to operate on the city water line or on a tank of water carried on the cart. The estimated through-put of the exchanger was about one gallon of water per minute. By means of a pair of four-way valves, it was possible to direct an air stream through the ventilated chamber or to direct it through an oxygen-absorbing pyrogallol solution, or to by-pass both the chamber and the pyrogallol solution. The probe of an oxygen meter was inserted in the air line at a position just downstream from the lower four-way valve, i.e., downstream from the ventilated chamber and pyrogallol solution.

At first, considerable difficulty was encountered in maintaining a constant level of water in the exchanger column, as for some reason, the quantity of air within the system did not remain constant. The difficulty was traced to what is referred to as "blow-by" past the pistons of the air pump. Piston-operating air pumps always lose or gain small amounts of air around the piston rings; but, for most uses of laboratory pumps, these small leaks are of no consequence. A small amount of blow-by would also have been of no consequence.for the countercurrent gas exchanger experiments had the pump been placed inside the ventilated chamber However, even had the latter remedy been considered for experimentation, the ventilated chamber was far too small to house the air pump. Hence, the piston pump was replaced by a peristaltic pump and the problem of leaks and fluctuating water level was no longer encountered.

In the first experiments, the countercurrent gas exchanger removed rather than replenished the oxygen in the chamber. If the oxygen content of the air in the ventilated chamber was initially 21 percent, it gradually fell to 5½ percent as water was run through the exchanger. However, it was later found that if the oxygen content in the chamber was first reduced to one percent by passing the air through the pyrogallol solution, it would then be elevated to about 5½ percent as water was run through the exchanger. Apparently, the feed water was only about 25 percent saturated with oxygen.

For later experiments water from the mains was first stored and aerated in a large sink. The aerated water was then pumped through the gas exchanger. Figure 2 compares the results of experiments performed with the aerated water and with the water from the mains supplying the Laboratory. The experiments clearly show that the gases dissolved in water can be employed to replenish the oxygen of a chamber previously depleted of oxygen.

A larger model of the countercurrent gas exchanger (Figure 3) was constructed and installed in a small shed on a corrosion dock in the Hueneme harbor where sea water was readily available. The peristaltic air pump proved inadequate for the most efficient operation of the larger model through which it was possible to pass an estimated six gallons of sea water per minute. Nevertheless, by continually scrubbing the air in the countercurrent gas exchanger, it was demonstrated that the air in a chamber previously flushed with nitrogen can be readily replenished with oxygen by exchange with the gases dissolved in sea water.

Venturi gas exchanger. The peristaltic pump was very noisy when operated at high speeds; it was wasteful of energy; it did not have the capacity that was desired; and it heated up when operated continuously for extended periods of time. Means were therefore sought to eliminate the need for a mechanical air pump and instead to utilize the stream of water to force air through the scrubber. A venturi pump or aspirator seemed the logical device for performing this operation; and after a few preliminary tests had been made with a small glass aspirator and other laboratory glassware, the construction of a prototype "venturi gas exchanger" was undertaken.

When the venturi gas exchanger was first constructed, it was inadequately provided with means to recapture air entrained in the discharge water. In consequence, considerable air was lost as small bubbles. This problem was overcome by the addition of a baffled tank, or air-water separator (Figure 4), to the system. A twelve liter flask equipped with an inlet and outlet was also added to the system to serve as a simulated underwater chamber; and a micro-burner, which served to simulate a man or animal, was placed in the flask. In lieu of the 12 liter flask, a large dessicator jar served as a simulated underwater chamber for some experiments.

The complete system is shown diagrammatically in Figure 5. Stale air is pumped from the chamber by means of a venturi pump, also called a venturi aspirator or injector, and then forced through the gas exchanger where the air is continuously scrubbed in a stream of sea water. Gases from the chamber and the gases dissolved in the sea water freely mix and interchange. Excess carbon dioxide in the stale air diffuses into the stream of sea water, and oxygen in the sea water diffuses into the oxygen-deficient stale air. The scrubbed and revitalized air, recharged with oxygen

is then returned to the chamber where it continues to supply oxygen to a flame (or man or animal). The only source of air in the chamber is that removed from the sea water by means of the venturi gas exchanger.

An attempt was made to sustain a flame in the flask, or chamber, ventilated by the venturi gas exchanger. It was first desired to know how long a micro-burner would burn on the oxygen contained within the system. Hence, the burner was ligh d and the same water was repeatedly recycled through the exchanger, but the water flow to the exchanger was turned off. The flame burned for 31 minutes. At the moment that the flame went out, the concentration of oxygen in the exhaust air was about 7 percent and the concentration of oxygen in the scrubbed air entering the chamber was about 10 percent. In two repeat tests the flame burned for 33 minutes and 34 minutes respectively. As in the first test, the concentration of oxygen of the scrubbed air entering the chamber was about 10 or 11 percent just before the flame went out; but the concentration of oxygen in the exhaust air was somewhat variable, ranging from about 6 to 10 percent. Slight changes in the air currents within the chamber probably influenced the amount of mixing that occurred in the current of air downstream from the flame, thereby causing fluctuations in readings on the lower oxygen meter.

Aerated sea water was then cycled through the gas exchanger at a rate of 8 gallons per minute; and, after the chamber was first flushed with atmospheric air, the burner was again lighted. During the first hour of operation, the oxygen content of the scrubbed air entering the ventilated chamber fell to 12 percent and the oxygen content of the exhaust air leaving the chamber fell to 7.5 percent. The concentration of oxygen in the incoming air then remained relatively constant at about 12 percent but the concentration of oxygen in the exhaust air drifted slowly to about 10 percent during the last few hours of the experiment (Figure 6). The flame burned for a period of 4 hours and fifteen minutes at which time it was purposely extinguished. All indications were that it would have continued to burn indefinitely.

The same experiment has been performed on many occasions; and, aside from minor fluctuations in the concentration of oxygen in the exhaust air, the results are usually about the same. Usually the flame burns until it is purposely extinguished, but on occasions it has gone out before that time. The capacity of the apparatus for recovering oxygen is just barely sufficient to sustain the smallest flame possible; and, if the valve regulating the fuel supply is inadvertently opened a trifle wider than necessary, the flame suffocat s itself.

To demonstrate that the air in the chamber can sustain life, two small rats were placed in the chamber in lieu of the micro-burner (Figures 7 and 8). On several occasions the rats were kept in the chamber for periods of several hours and on one occasion they were kept in the chamber for an entire 8 hour day. In the experiments with the rats the concentration of oxygen of the scrubbed incoming air leveled off at about 18 percent and the concentration of oxygen of the exhaust air leveled off at about 17 percent. The rats appeared to be comfortable during the experiments, and when they were examined several weeks later, they appeared to be in good health.

ANALYSIS OF THE EXPERIMENTAL RESULTS

The fact that a flame and small laboratory animals could be maintained in the ventilated chamber for extended periods of time is considered evidence that the sea water was supplying oxygen to the chamber and removing carbon dioxide. The fact that the animals suffered no apparent ill effects is considered evidence that the air in the chamber was not acutely toxic and that air so generated is habitable for periods of at least eight hours.

The total volume of air in the chamber and gas exchanger was about one cubic foot. Initially, the air contained about 0.2 cubic feet of oxygen, and approximately half of this oxygen was used up by the flame in about one-half hour. Thus the flame consumed oxygen at a rate of about 0.2 cubic feet per hour. Fuel consumption by the microburner was too small to be measured by flow meters that were available, but an estimate of the flow rate of the acetylene gas used in the burner was made by collecting the fuel over water in a graduated cylinder. Forty milliliters of the gas were collected in one minute, a collection rate equivalent to 0.08 cubic feet per hour. If the gas were completely burned to carbon dioxide and water, oxygen would be consumed at a rate of about 0.22 cubic feet per hour. If, however, the gas were merely burned to carbon monoxide and water, oxygen would be consumed at a rate of about 0.13 cubic feet per hour. Estimates of the rate of oxygen consumption by the flame can also be made from the data of Figure 6. When no water was flowing to the exchanger and the burner was consuming only the confined oxygen, the oxygen concentration of the air in the chamber fell from approximately 20 percent to approximately 10 percent in one half hour. This fall corresponds to an oxygen consumption of 0.2 cubic feet per hour. Later, when the air in the chamber was scrubbed with aerated sea water, the oxygen concentration of the air rose from about 10 to about 12 percent in six minutes. From these values it was calculated that oxygen was being recovered at a rate of 0.2 cubic feet per hour. Thus the estimates for the rate of oxygen consumption based on the time for the flame to go out, the rate of fuel consumptiom, the rate of fall of the oxygen concentration, and the rate of recovery of oxygen were all in fair agreement.

The oxygen concentration of the incoming sea water, which was circulated through the exchanger at a rate of 8 gallons per minute, was about 8 milliliters per liter. From these values it was calculated that the total volume of oxygen dissolved in the sea water that passed through the exchanger in one hour was about 0.5 cubic feet. Thus about 40 percent of the oxygen must have been removed from the sea water to support the flame. This value is in fair agreement with data obtained by direct chemical analysis of the incoming and outgoing sea water.

Data obtained aboard submarines indicates that one man requires about one cubic foot of oxygen per hour. This, of course, is an average value for a 24 hour period, and the average applies to submarine crews housed in warm quarters. During or immediately after a work period, a scuba diver might require ten cubic feet of oxygen per hour, as he would consume oxygen at an accelerated rate in consequence of his physical activity, and he would also require extra oxygen to support the metabolic processes keeping him warm. Thus, a scuba diver resting in an undersea shelter might require an oxygen supply 50 times greater than was supplied to the micro-burner in the experiments just described. However, a supply 5 to 10 times greater would probably meet his average needs. Hence, a venturi gas exchanger operating at the same efficiency as the one described would need to process a minimum of 40 to 80 gallons of air-saturated sea water per minute to supply one diver with oxygen.

The principle of ventilating a chamber with a gas exchanger is in essence that fresh air is stripped or purged from sea water with "stale" air. The "staler" (i.e., the more deficient in oxygen) the exhaust air, the more efficient is the stripping process. The concentration of oxygen of the exhaust air in the chamber in which the flame was burning fell to below 12 percent, a concentration in which man could not survive. To be comfortable at atmospheric pressure, man would require air containing about 18 percent oxygen. The stripping or purging efficiency of a venturi gas exchanger supplying oxygen to a man would therefore be much lower than that of the exchanger supplying oxygen to the gas micro-burner. There are several things that can be done to compensate for this, however:

a. The volume of sea water pumped through the system can be increased several fold.

b. The air from the gas exchanger can be pumped into living chambers maintained at pressures of from two to four atmospheres. Two atmospheres are equivalent to the submergence pressure at a depth of about 30 feet in the ocean; three atmospheres, at a depth of about 60 feet; and four atmospheres, at a depth of about 90 feet. At these pressures man would require air containing about 10, 7, and 5 percent oxygen, respectively; he would

in fact, suffer discomfort if the oxygen concentrations were markedly higher. Thus, at these pressures, the concentration of purging air could be maintained sufficiently low for efficient operation of the venturi gas exchanger. At least down to three atmospheres of pressure, and probably down to four, man would probably not require mixtures of helium and air for breathing.

c. An air separator could be added to the system. The oxygen would thereby be removed from the exhaust air before the air was vented to the gas exchanger and the oxygen could then be returned to the ventilated chamber. With a system consisting of a venturi gas exchanger and an efficient gas separator, essentially all of the oxygen could be removed from the sea water. Though the required air separators are not yet available, indications are that they will be available in the not-too-distant future.[1]

d. Man himself could function as an air separator by wearing a special face mask. He would exhale his exhaust air directly into the intake of the gas exchanger, and he would inhale air directly from the discharge port of the gas exchanger.

POTENTIAL USE OF THE VENTURI GAS EXCHANGER

The greatest and most immediate potential use for the NCEL sea water process for supplying air underwater is to ventilate undersea shelters or rest stations for divers working at depths of less than 100 feet. Maintaining a ship and crew to supply air to divers engaged in routine construction tasks in relatively shallow water is rather costly; yet, even in shallow water, it is not efficient for the divers to surface for rest after only a few hours of work. The Man-in-the-Sea Program has indicated that the work output of divers provided with submergence pressure rest stations is 10 to 20 fold greater than the output of divers who must surface to rest. The venturi gas exchanger has great potential as a very economical device for ventilating submergence pressure rest stations in relatively shallow water.

The need for an improved air supply system in relatively shallow water is being neglected by both the Man-in-the-Sea and the Submarine research programs. The greatest research effort is being devoted to getting man deeper,[8] but the greatest undersea activity will probably occur at shallow depths as shallow regions of the ocean are more accessible. Highways and pipelines paralleling the shore will be constructed in shallow waters; oil wells in the North Sea and in the Gulf of Mexico will be drilled in shallow seas; and coastal surveillance stations, as for example in southeast Asia, will perhaps be constructed in shallow water. The venturi

gas exchanger should be a suitable device for supplying air for all of these activities. A venturi gas exchanger might also be employed to ventilate a below-surface station servicing lines to deeper Man-in-the-Sea stations. The below-surface station, at depths just deep enough to escape storms, would require only an electric power line from shore. Helium tanks could be lowered to it during fair weather, and from there, the helium could be metered to the deeper station during fair or stormy weather.

At greater depths than about 100 feet, the venturi gas exchanger could not be employed to ventilate rest stations for scuba divers unless a suitable air separator could be developed for recovering helium, as divers require breathing mixtures of helium and air at these depths. Recently developed membranes enhance the chances for the successful development of the required air separator.

The venturi gas exchanger could also be used at any depth to ventilate a "hard shelled" shelter in which the ambient pressure is maintained at or near the pressure existing at the surface. With presently available pumps, however, the power requirements would be prohibitive at depths of greater than a few hundred feet. Successful development of the NCEL pressure-reducing pump (Navy patent disclosure No. 38365)[7] would reduce the cost of circulating water in the system by means of pressure compensating pistons. The only limit on depth for the potential usefulness of the venturi gas exchanger would then be the structural integrity of the shelter and pistons and frictional forces introduced by water pressures at great depths.

PLANS FOR THE FUTURE

The experimental gas exchanger assembly described previously in this Technical Note (Figures 4, 5, 7, and 8) cannot be operated underwater. Several changes must be made in its design and several control devices must be added before it can be operated while submerged. Immediate plans are to construct a new venturi gas exchanger assembly that is small, easy-to-handle, and fully instrumented. The unit or assembly will include a gas exchanger, a ventilated air chamber, and a baffled air-water separator - all designed to function underwater.

Tentative plans for the new unit are shown in Figure 9. With the exception of the ventilated chamber, the entire unit will be mounted inside the baffled box comprising the air-water separator. The box will be about three feet long, twelve inches wide, and eighteen inches high.

Sea water was pumped "into" the previously described gas exchanger, and the water was removed by gravity flow. In contrast, it would not be necessary to pump water into a submersible gas exchanger unit if it were

operated at a depth of 40 feet or more; but it would be necessary to pump water from the unit. Hydrostatic pressure would force the sea water into the unit with sufficient thrust to operate the venturi air-injector; but gravity flow would have insufficient thrust to remove the sea water against the pressure of submergence. If the gas exchanger unit were submerged in much less than 40 feet of water, however, the thrust of the water would be insufficient to operate the venturi injector; and pumps would be required for pumping water into the unit, as well as for removing water from it.

Two centrifugal water pumps, each rated at 1/8 horsepower, will be incorporated in the venturi gas exchanger unit now being designed. Provisions will be made to operate either one or both of the pumps, depending upon the depth (or simulated depth) of submergence. Both pumps will be mounted inside the air-water separator. All of the heat produced by the pumps will thereby be captured by the water and will help to drive air from the water.

Pumping of water from the venturi gas exchanger unit must not be permitted to proceed past the intake port of the discharge pump, as air instead of water would then be pumped from the system. On the other hand, water entering the system must not be permitted to reach the air-line leading to the air chamber. Hence, two sets of conductivity probes will be employed to control the water level in the air-water separator of the unit now being designed. One set will shut off the intake pump, A, when the water level rises too high; and the other set will shut off the discharge pump, B, when the water level falls too low. Both pumps will operate at intermediate water levels.

The intake water will be forced through a venturi injector which will be discharged through a parallel "coil" of pipe sufficiently long to permit adequate exchange of gases; but the coil must not be so long as to create a back-pressure of more than seventy-five percent of the water pressure at the discharge port of the intake pump. The coil will consist of parallel sections of pipe extending the full length of the baffled air-water separator. Space will be provided for two, four, or six lengths of pipe so that comparisons can be made of the effect of coil length.

Air pressure in the gas exchange column, in the baffled air-water separator, and in the ventilated chamber of the previously described unit (Figure 5) were all maintained at approximately atmospheric pressure. This simple procedure eliminated the need for an auxiliary air pump and eliminated the need for numerous back-pressure valves and water level control devices. However, a near uniform air pressure could not be maintained throughout a venturi gas exchanger unit submerged in the ocean. If the ventilated chamber is to serve as an underwater shelter for scuba divers,

its interior atmosphere must be maintained at the pressure of submergence, a pressure significantly greater than atmospheric pressure. On the other hand, if the air pressure within the baffled air-water separator exceeded one atmosphere, more air would diffuse into the sea water than would diffuse from it and there would be a net loss of air from the system. Thus, valves will be required to regulate the flow of air both from the air-water separator and from the ventilated chamber, and a pump will be required to pump the air from the baffled air water separator up to the pressure existing in the ventilated chamber. In the unit now being designed, a one-sixth horsepower pump, mounted inside of the ventilated chamber, will be employed for the latter purpose.

If the air-pressure within the air-water separator were considerably lower than atmospheric, more air would diffuse from the sea water than would diffuse into it, and there would be a net gain of air in the system. In consequence, the water level in the ventilated chamber would fall. In the immediate future, overflow air will simply be permitted to bubble to the surface. However, it is anticipated that a regulator can be developed for maintaining a constant volume of air in the ventilated chamber. The regulator will automatically adjust the setting on the back-pressure valve, thereby regulating the air pressure in the air-water separator. Air from the ventilated chamber could then be pumped into scuba tanks, and the resulting loss of air from the chamber would initiate the regulator to temporarily cause a higher vacuum in the air-water separator. The air used up to charge the scuba tanks would subsequently soon be replaced.

Sea water has a great capacity to absorb carbon dioxide, as is evidenced by the extremely low concentration of that gas in the earth's atmosphere. However, scrubbing with sea water will not reduce the concentration of carbon dioxide in a closed chamber to low levels unless the air in the chamber is cycled through the sea water with sufficient frequency.

The concentration of oxygen in a soft-shelled shelter, submerged to sixty feet and ventilated by a venturi gas exchanger, can be "breathed down" from a theoretical maximum of 21 percent to about 7 percent. However, in the process, the concentration of carbon dioxide could build up to as high as 14 percent, a lethal concentration of that gas. In a chamber pressurized under a 60 foot head of water, the maximum concentration of carbon dioxide that could be tolerated by man would hot exceed one percent, and even one percent might be uncomfortable at that pressure.

Hence, to remove carbon dioxide from the chamber of Figure 10, it will be necessary to cycle the air through the venturi gas exchanger more frequently than would be required merely to purge oxygen from the sea water. The minimum flow of air through the chamber must be about two cubic feet per man per minute, based on the volume of air at the pressure of submergence. (Experimental data concerning ventilation rate requirements for submerged structures should be forthcoming from the Man-in-the-Sea Projects.)

Assuming that the air compressor of the apparatus shown in Figure 9 has more than sufficient capacity to force air through the chamber at the required rate, the adjustable orifice-valve will control the ventilation rate. Ideally, the opening of the valve would be regulated by the carbon dioxide concentration within the ventilated chamber. Carbon dioxide sensors capable of regulating a valve are commercially available; but they are rather costly for installation on experimental equipment. Hence, for the time being, the valve will be adjusted manually.

It is anticipated that a simple bubbler-flask, containing sea water and a few drops of brom-thymol-blue indicator solution, can be employed to estimate the carbon-dioxide concentration in the ventilated chamber. The mixture will be blue when the concentration of carbon dioxide in the air is low, and yellow when the concentration of carbon-dioxide is high. A yellow to yellowish green color will indicate that the air is unsafe for breathing, and a greenish-blue to blue color will indicate that the air is safe to breathe (i.e., safe from the standpoint of carbon dioxide content).

Although it is planned to submerge the unit either in the ocean or in a large tank of sea water, it will be possible to perform various tests without actually submerging the unit. A back pressure valve will be added to the discharge line to simulate discharge at various depths and the feed-water will be supplied under various pressures. Thus the operating characteristics of the unit can be tested at various simulated depths. However, the small pumps that will be used will not permit operation at depths of more than about twenty feet. The main function of the unit will be to evaluate the general design of the valving arrangement for regulating the simultaneous flow of water and air through the various pressure changes.

It is anticipated that the small venturi gas exchanger unit now being designed will operate most efficiently at a depth of about eight feet and with a five pound vacuum maintained in the air-water separator. Under these conditions both the centrifugal pumps will have about the same work load and together they will force sea water through the system at an estimated rate of three to five gallons per minute. Because the pressure maintained in the ventilated chamber will be higher than was maintained in the chamber in the experiments described previously, and because the air-water separator will be lower than in the former experiments, it is anticipated that the new gas exchanger unit will perform more efficiently than did the former unit.

Should the valving arrangement and performance of the unit prove satisfactory, a larger unit of similar design will be constructed. It is anticipated that the larger unit will be constructed with the capacity to process about 200 gallons of sea water per minute when submerged at a depth of sixty feet. A five horsepower centrifugal pump would have the required capacity for pumping the sea water, and it is estimated that a five horsepower air compressor will be required to circulate the air at that depth. The unit would perhaps be capable of supplying air to at least two men at that depth.

REFERENCES

1. U. S. Naval Civil Engineering Laboratory, Port Hueneme, California. Technical Note TN-543, "A Proposed System for Supplying Air to a Hypothetical Underocean Seabee Base," by Harold P. Vind and Mary Jane Noonan. 8 November 1963.

2. Log of the Aquanauts, Naval Research Reviews, September 1964, pp. 16-24, Vol. XVII, No. 9.

3. "Sealab I," Naval Research Reviews, July 1964, pp. 5-9, Vol. XVII, No. 7.

4. School of Aviation Medicine, Randolph AFB, Texas. No. 58-126. "The Provision of Respiratory Gas Exchange for Small Primates by use of a Photosynthetic Gas Exchanger," by Robert D. Gafford, Captain, USAF; H. L. Bitter, Captain, USAF; and Robert M. Adams, M. A.

5. NRL Report 5954. "A Study of the Feasibility of Oxygen Production by Algae for Nuclear Submarines," by R. J. Hannan, R. L. Shuler, and C. Patouillet. 12 August 1963.

6. Soule, Gardner (describing research of Dr. Walter L. Robb, General Electric Research Laboratories, Schnectady, New York), "Hamster in a Fish Tank," Sea Frontiers, Vol. 11, No. 2 March-April, 1965, pp. 102-107.

7. Patent Application, Navy Case No. 38365, Serial 51154, 16 February 1965. Pressure Reducing Pumping System. Inventors: William B. Plum and Harold P. Vind, Employees of the U. S. Naval Civil Engineering Laboratory, Port Hueneme, California

8. Booda, Larry L., Associate Editor. "Man-in-the-Sea Projects Will Go Deeper, Stay Longer," Undersea Technology, Vol. 6, No. 3, March 1965, pp. 15-19.

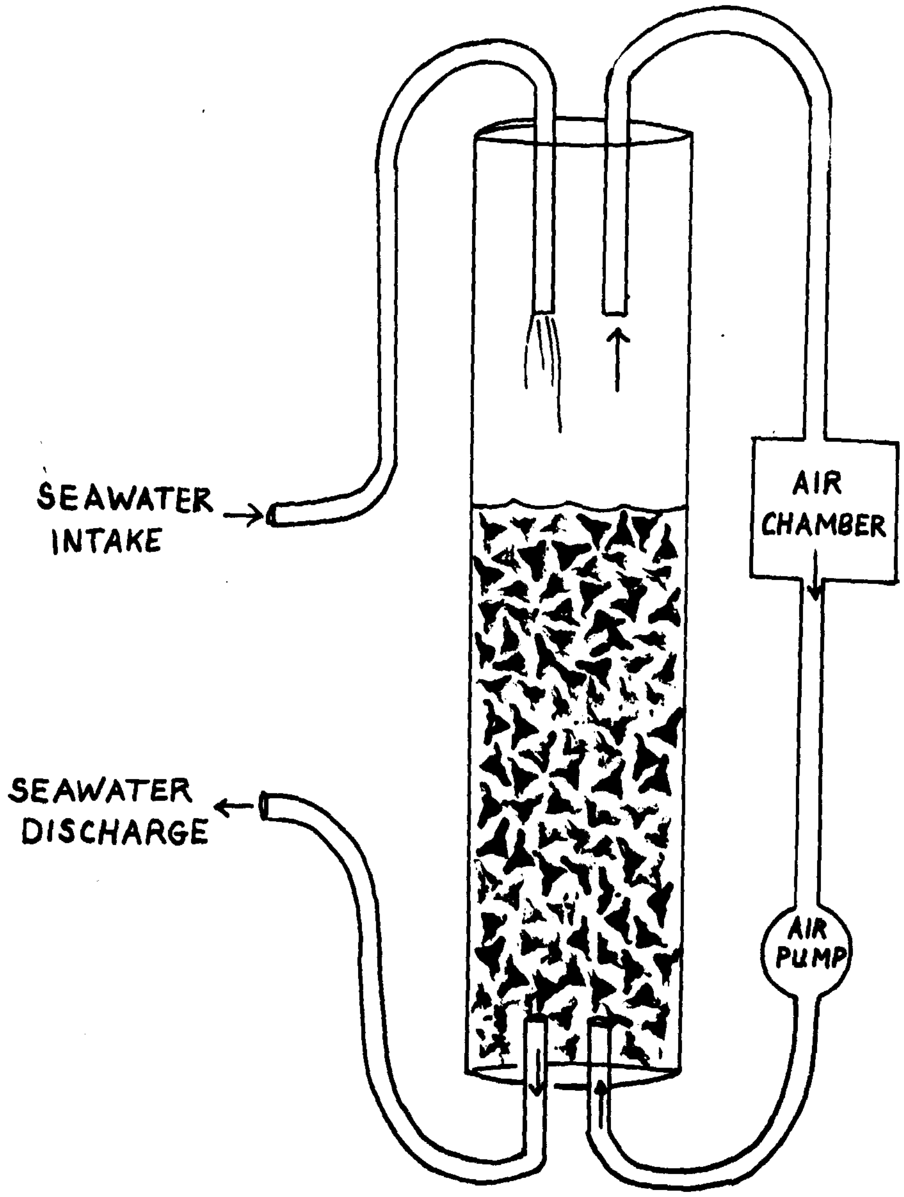

Figure 1. Countercurrent gas exchanger

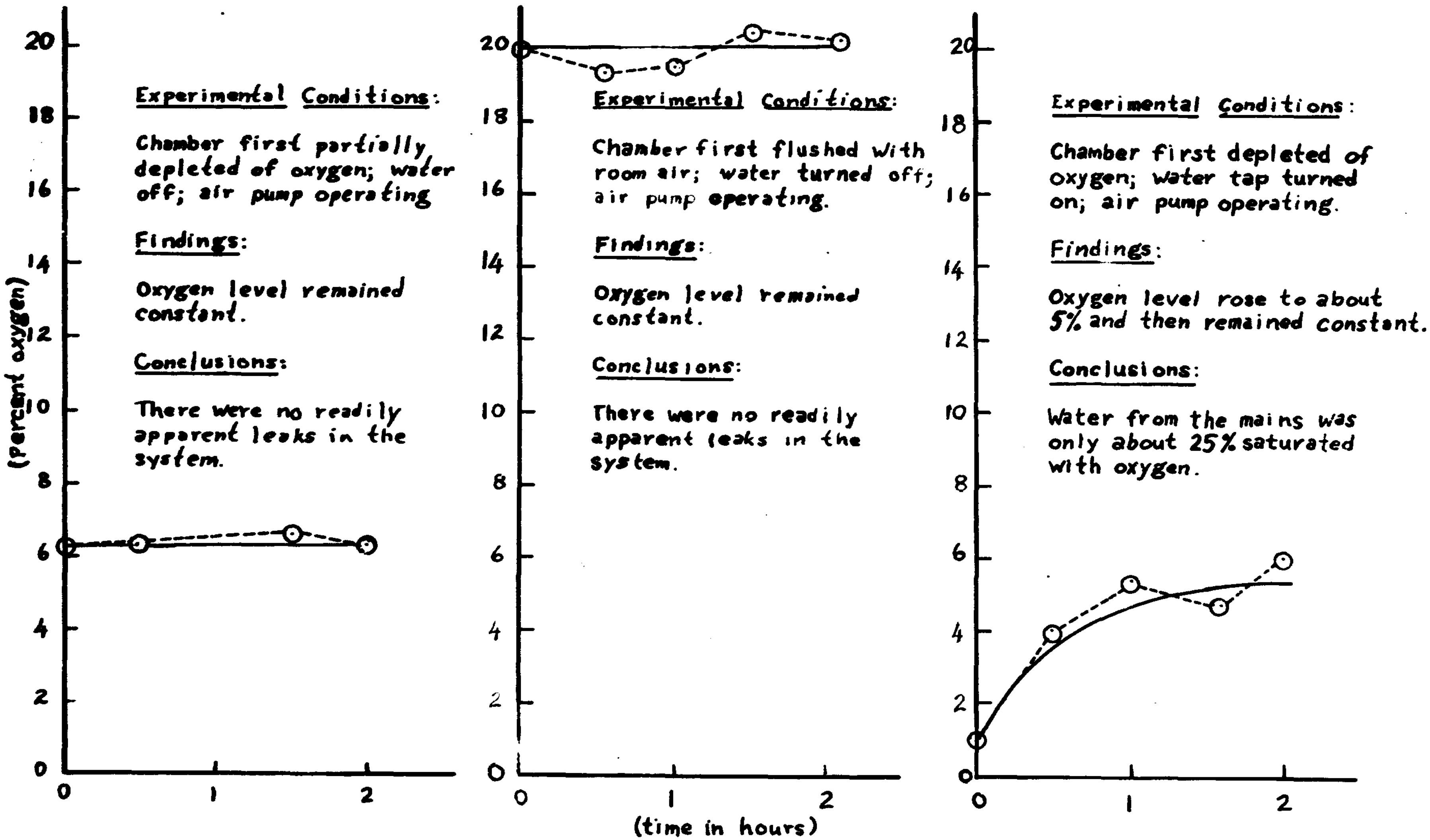

Figure 2. Graphical representation of the results of experiments demonstrating that the gases dissolved in water can be employed to replentish the oxygen of a chamber previously depleted of oxygen.

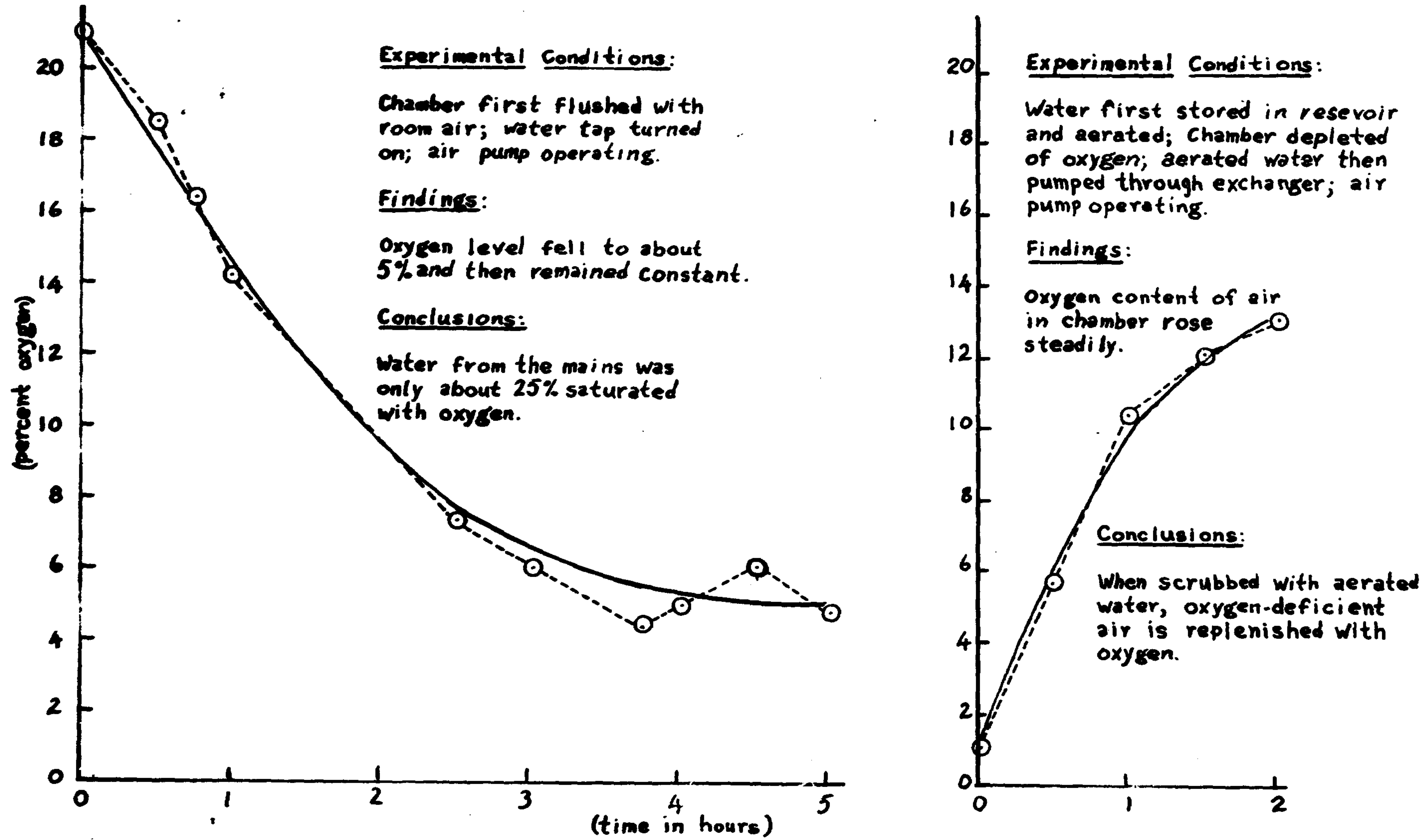

Figure 2 (cont.) Graphical representation of the results of experiments demonstrating that the gases disolved in water can be employed to replentish the oxygen of a chamber previously depleted of oxygen.

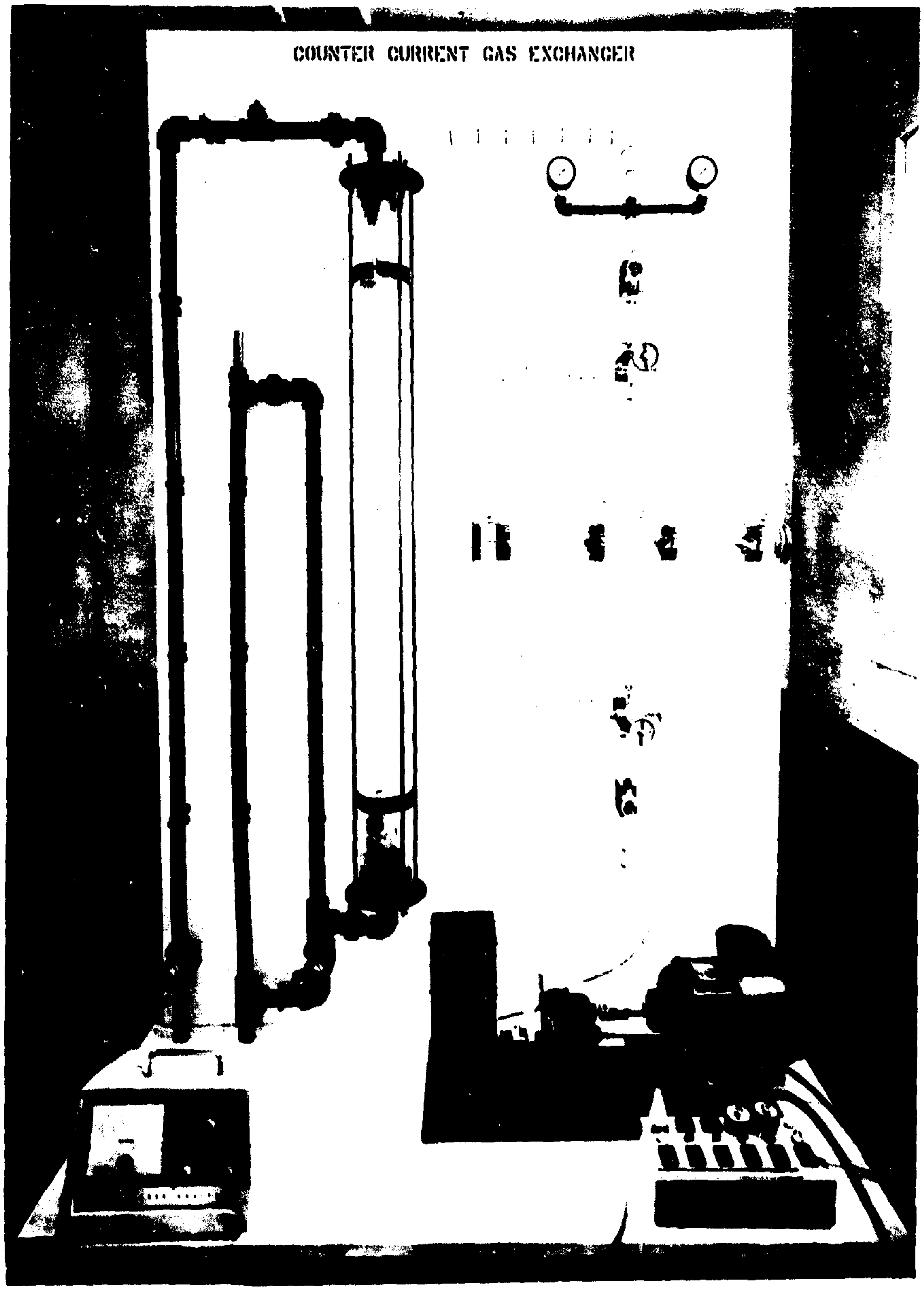

Figure 3. Countercurrent gas exchanger unit operated in small shed on the pier at Port Hueneme.

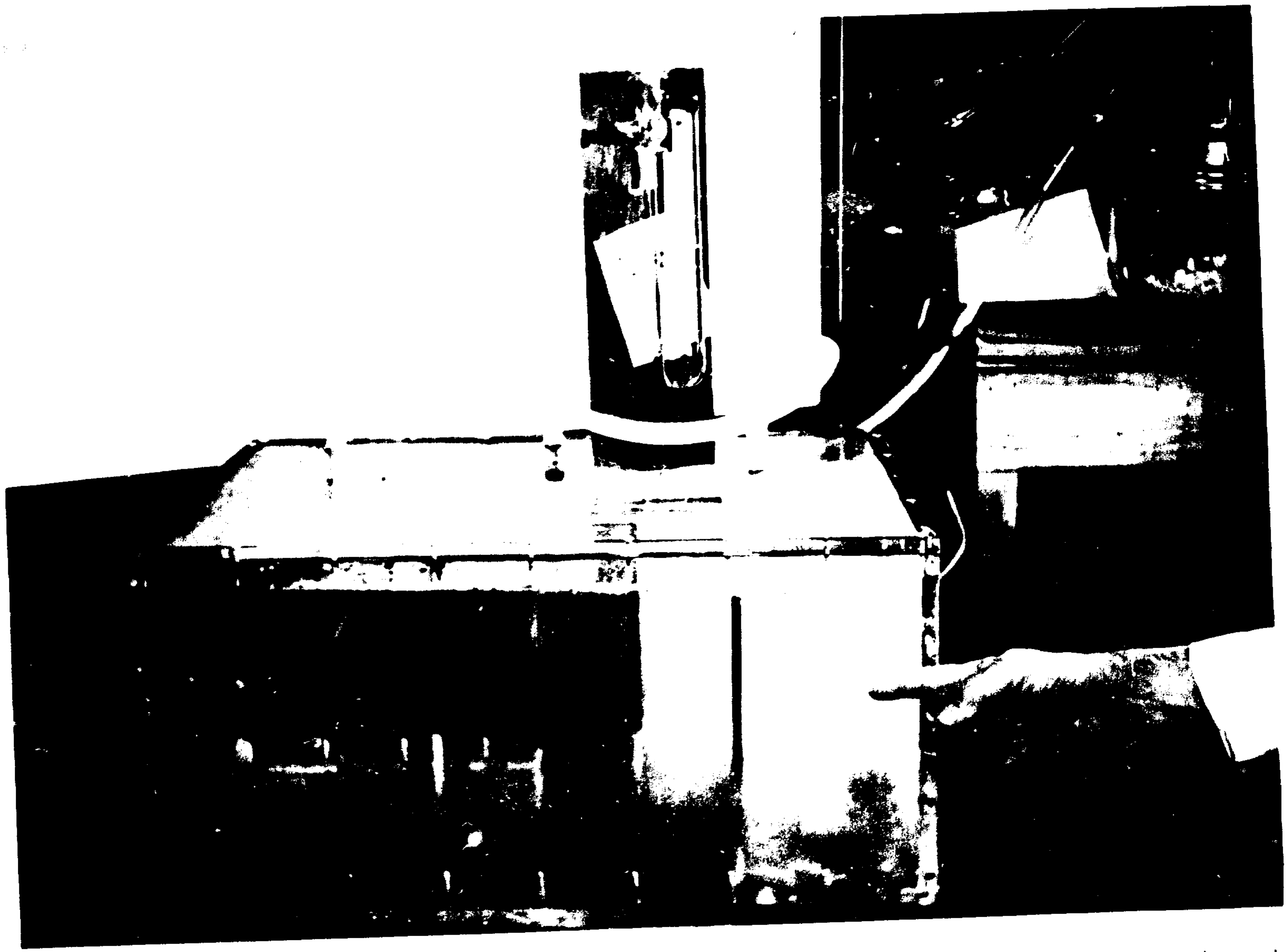

Figure 4. Baffled air-water separator for recovering air entrained as small bubbles in the sea water discharged from the venturi gas exchanger column.

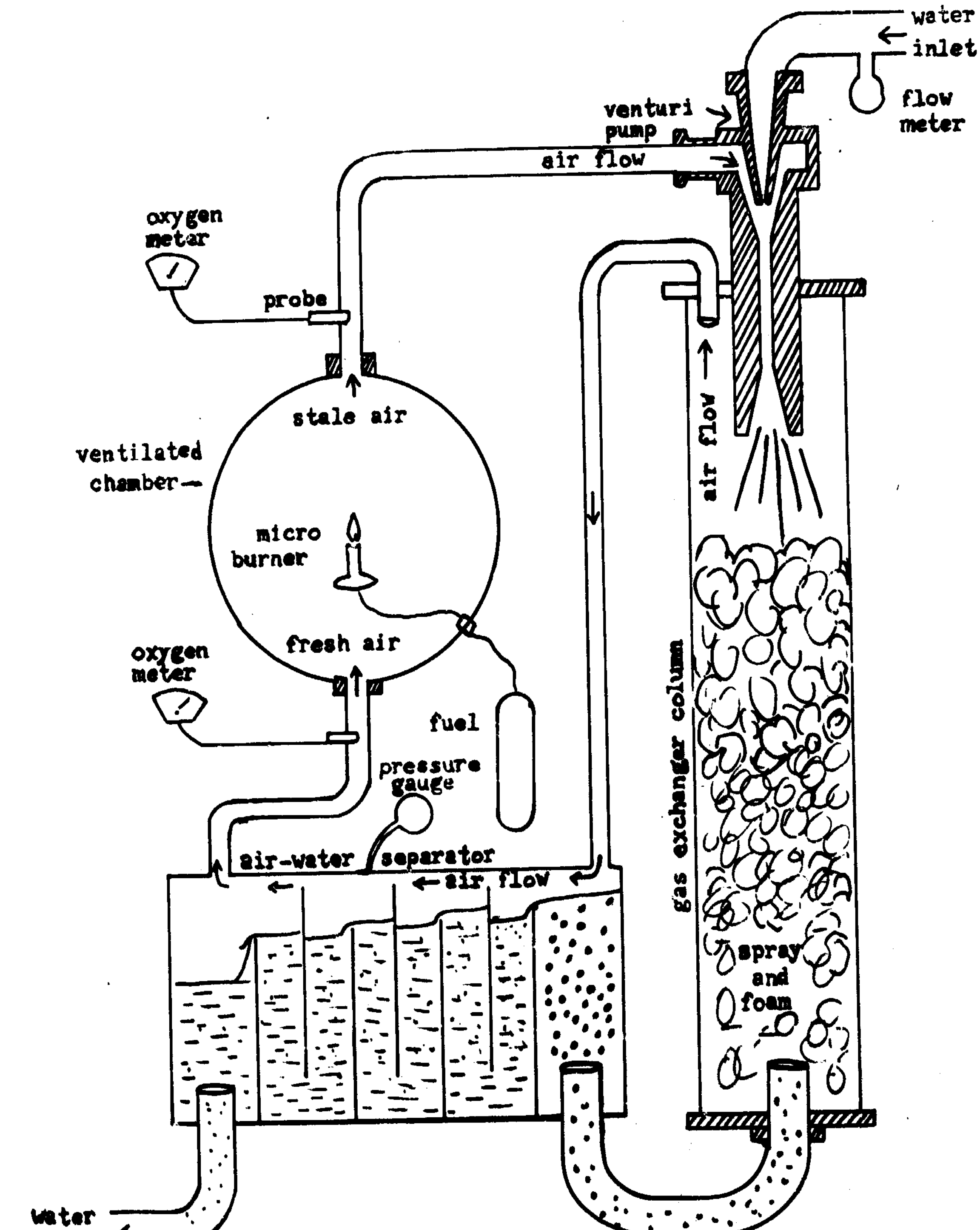

Figure 5 Diagramatic sketch of chamber ventilated by means of a venturi gas exchamber

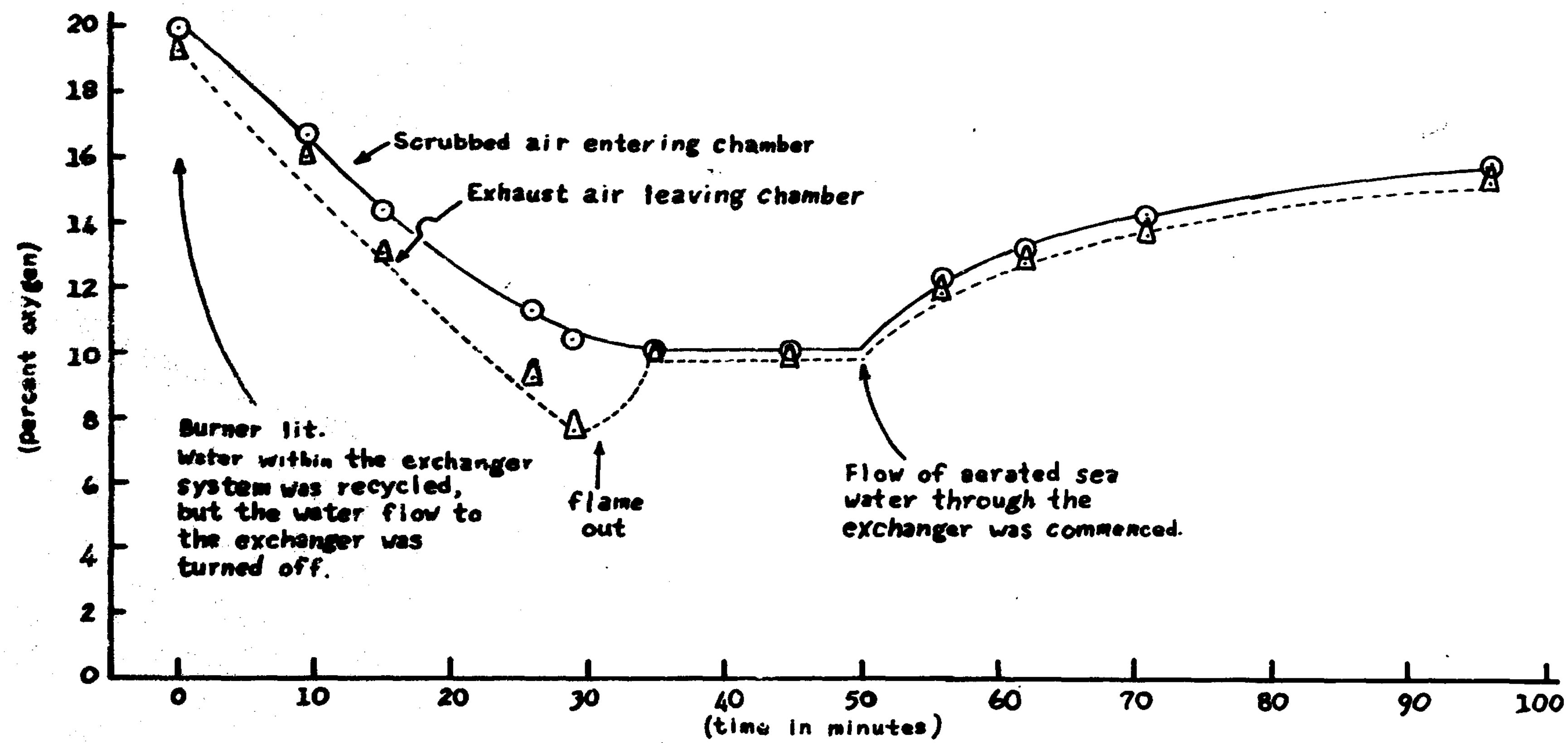

Figure 6 Graphical representation of the results of experime 's in which a flame was sustained on oxygen recovered from sea water. (continued on next page).

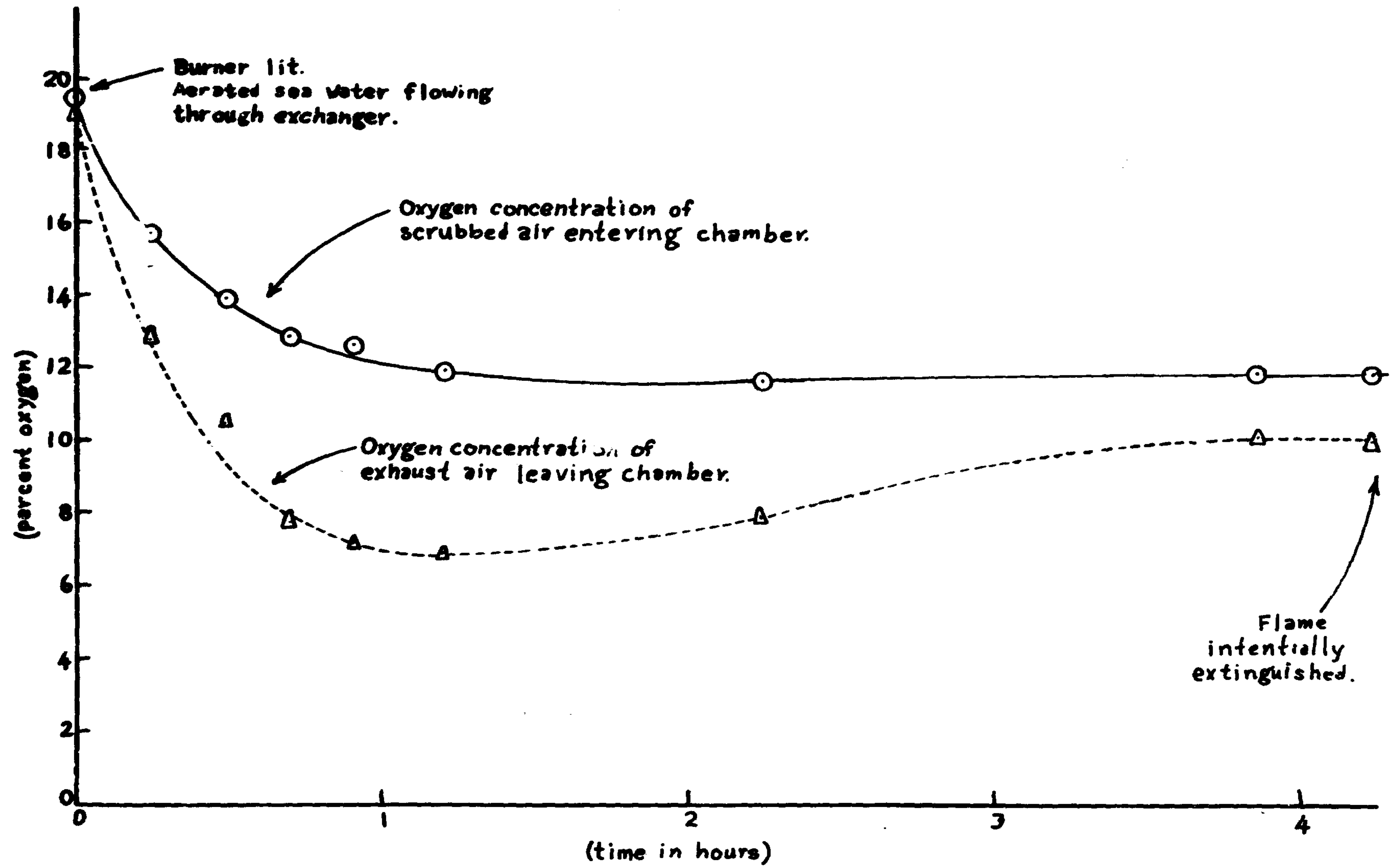

Figure 6. (continued) Graphical representation of the results of experiments in which a flame was sustained on oxygen recovered from sea water.

Figure 7. The authors test the ability of the venturi gas exchanger to ventilate a small chamber in which two rats are breathing.

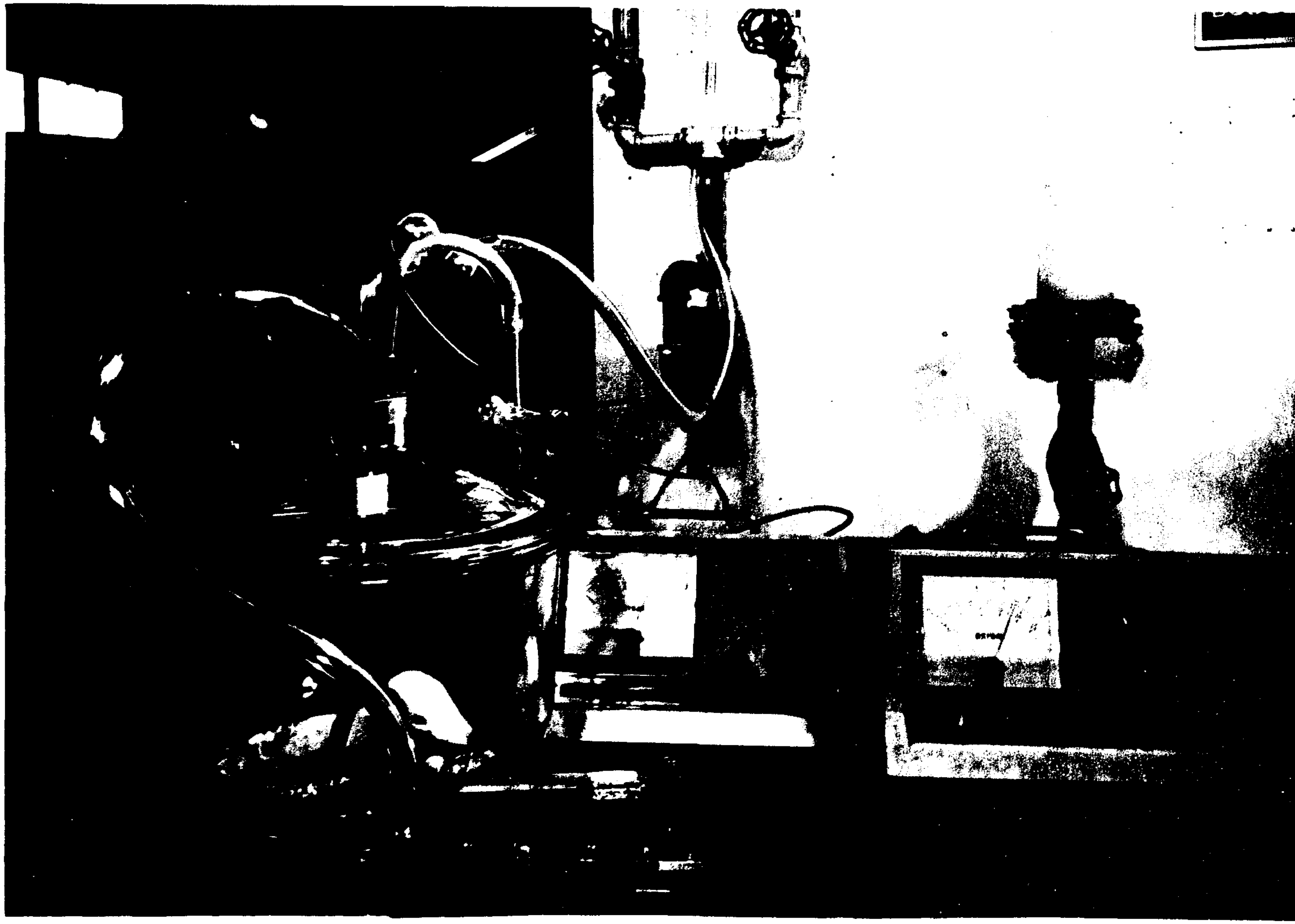

Figure 8. Close-up view of the rats in the chamber ventilated via the venturi gas exchanger.

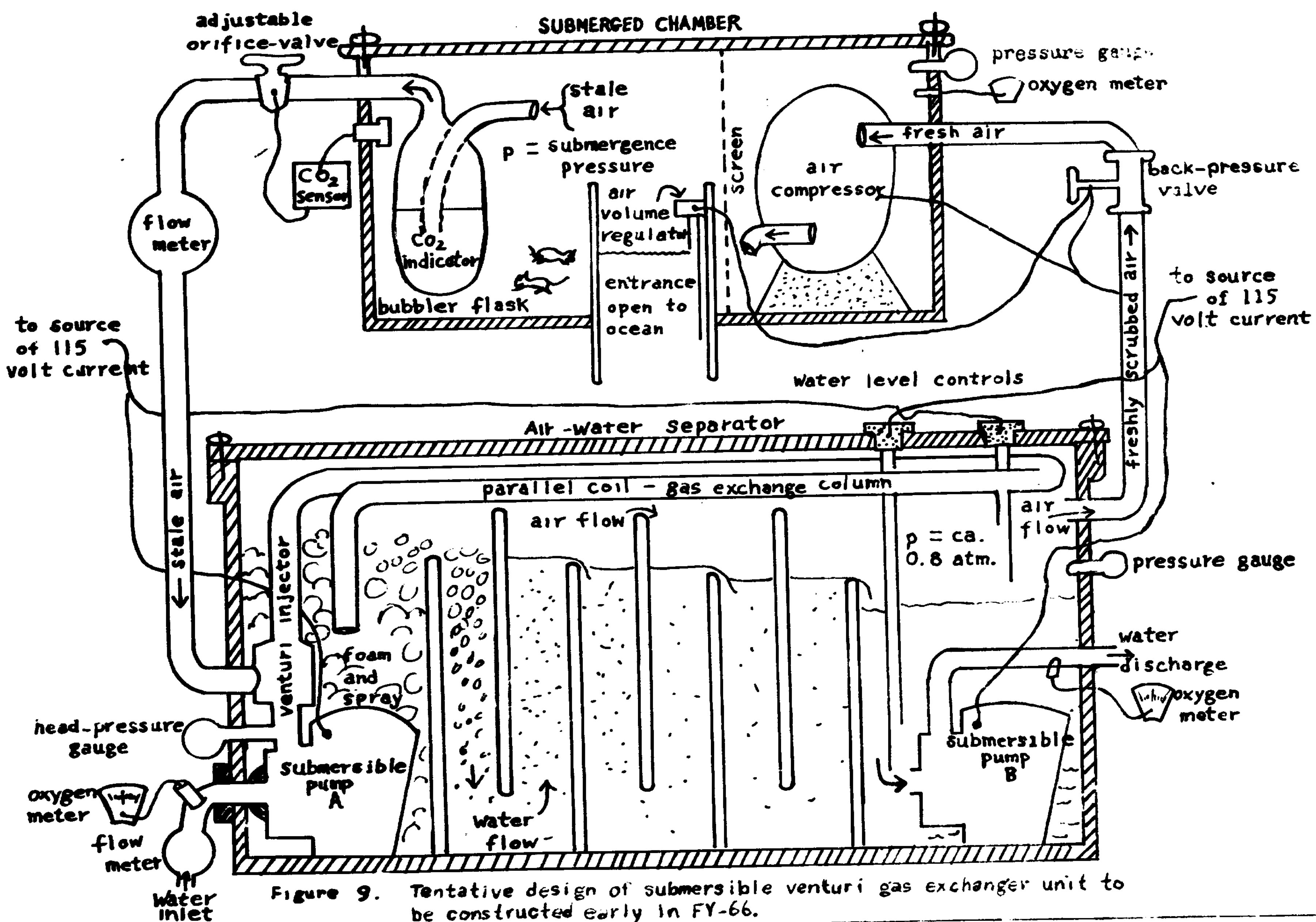

Figure 9. Tentative design of submersible venturi gas exchanger unit to be constructed early in FY-66.

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* U. S. Naval Civil Engineering Laboratory, Port Hueneme, California	2a. REPORT SECURITY CLASSIFICATION: Unclassified
	2b. GROUP

3. REPORT TITLE

A PROPOSED SYSTEM FOR SUPPLYING AIR TO A HYPOTHETICAL UNDEROCEAN SEABEE BASE. II. THE VENTURI GAS EXCHANGER

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Interim 1963 July - 1965 July

5. AUTHOR(S) *(Last name, first name, initial)*

Vind, Harold, P., and Langguth, Arthur

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
16 June 1965	26	8

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. Y-R011-01-01-058	TN-734
c.	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d.	

10. AVAILABILITY/LIMITATION NOTICES

Qualified requestors may obtain copies of this note from DDC.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	BuDocks

13. ABSTRACT

A device called a "venturi gas exchanger" was designed and constructed. The function of the device is to continuously scrub the interior atmosphere of a simulated underwater chamber in sea water. The only source of oxygen in the experimental chamber is that removed from the sea water during the scrubbing process, and the only means for removing carbon dioxide from the chamber is the same scrubbing process. A micro-burner can be kept burning indefinitely in the chamber; and two rats were maintained in the chamber for an entire eight hour day. During their stay in the chamber, the rats appeared to be comfortable and they suffered no discernible ill effects from the experience. Future plans call for the construction of a submersible model of the venturi gas exchanger which will be employed to ventilate a submerged manned enclosure.

DD FORM 1 JAN 64 1473 0101-807-6800

UNCLASSIFIED

Security Classification

SUPPLEMENTARY

INFORMATION

U. S. NAVAL CIVIL ENGINEERING LABORATORY
PORT HUENEME, CALIFORNIA 93041

IN REPLY REFER TO:
L70/dn
Y-R011-01
SERIAL 1790
AUG 31 65

AD 467500

From: Commanding Officer and Director
To: Defense Documentation Center, Cameron Station, Alexandria, Virginia 22314

Subj: Annual Report, FY-65, Navy Laboratories Research Y-R011-01, August 1965; forwarding of supplementary information on

Encl: (1) Revised Table of Contents (20 copies)
(2) Work Unit Y-R011-01-01-058, Undersea Air Supply (pages 38a and 38c)(20 copies)

1. Enclosure (1) is a revised table of contents for subject report.

2. One work unit was inadvertently omitted and is forwarded as enclosure (2).

J D Andrews

11ND-NCEL-10460/1 (REV. 4-63)

CONTENTS

Revised 8/20/65

Y-R011-01-01-058, Undersea Air Supply

The objective is to ascertain the feasibility of utilizing the air dissolved in sea water as a source of oxygen for manned undersea chambers and of subsequently utilizing the deoxygenated sea water as a vehicle to remove carbon dioxide.

A device called a "venturi gas exchanger" was designed and constructed. The function of the device was to continuously "scrub" the interior atmosphere of a small enclosed chamber in sea water (Figure 1). The only air in the chamber was that removed from the sea water during the scrubbing process, and the only means for removing carbon dioxide from the chamber was the same scrubbing process. Numerous tests and experiments were performed with the venturi gas exchanger.

A micro-burner can be kept burning indefinitely in the chamber ventilated by the sea water process, and two rats were maintained in the chamber for an entire eight hour day (Figure 2). During their stay in the chamber the rats appeared to be comfortable and they suffered no discernible ill effects from their experience.

The aforementioned venturi gas exchanger assembly was not operated underwater. Several changes must be made in its design and several control devices must be added before it can be operated while submerged. Immediate plans are to construct a new venturi gas exchanger unit that is small, easy to handle, fully instrumented, and designed to function underwater. Ultimate plans are to construct a unit large enough to ventilate a small manned structure submerged at shallow depths in the ocean.

Principal Investigator - H. P. Vind

TN-734, H. P. Vind and A. Langguth, "A Proposed System for Supplying Air to a Hypothetical Underocean Seabee Base. II. The Venturi Gas Exchanger", 16 June 1965

Figure 1. The air in the chamber is continuously scrubbed with sea water by means of a venturi gas exchanger

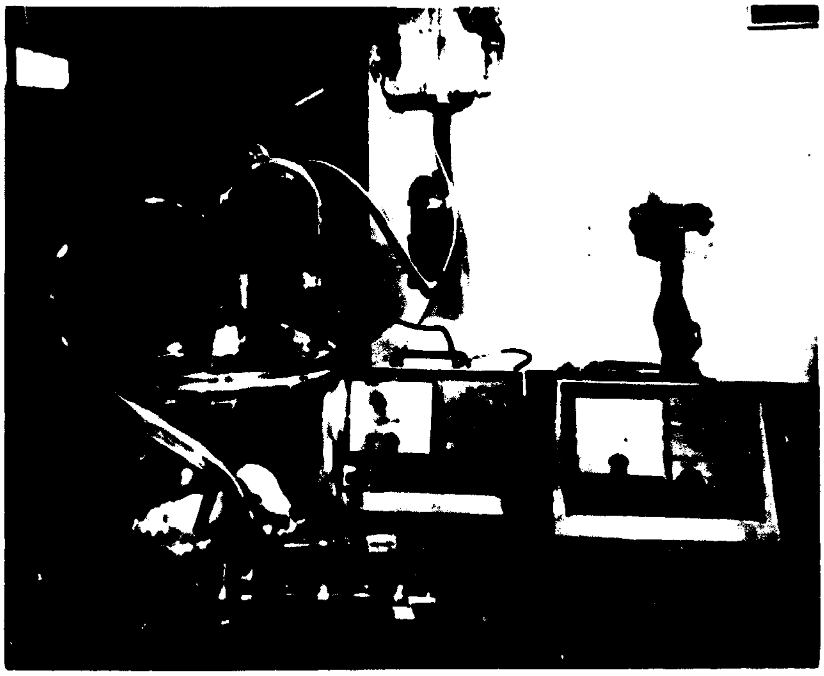

Figure 2. Close-up view of the rats in the chamber ventilated by the venturi gas exchanger